HMR WATER QUALITY – QUANTIFICATION OF DESIGN BENEFITS

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Overview

Meeting Lake Tahoe water quality improvement targets requires new tools, new approaches and a level of accountability currently under development. Here we compare analyses of possible sediment/fines/nutrient loadings from the proposed Homewood Mountain Resort (HMR) Ski Area Master Plan Project (Project) on the Lake Tahoe West Shore for standard 20-year/1-hour (20-yr) Best Management Practices (BMP) design and alternative project design approaches using a combined upslope-urban local watershed model. With this approach, we hope to suggest a means by which treatment/loading assumptions can be tested and performance evaluated that will set a robust starting point for what is intended to be a model water quality protection and improvement program for the Lake Tahoe Basin.

As with all modeling efforts, the accuracy these types of assessments depend on available data, the types of assumptions made in the calculations and the understanding of the functionality of the treatment elements within the stormwater quality 'treatment train'. This modeling effort transcends typical approaches in that we model across different climatic and soil moisture regimes, thus producing a model output that more closely approximates natural variability. Thus, the intent is to provide more realistic data that can be used as a foundation for post project monitoring and assessment.

Here, we employ the adjusted PRISM (Parameter-elevation Regressions on Independent Slopes Model)) precipitation data from past wet and dry year examples (1995 & 2006 (wet), and 1994 & 2003 (dry) water years or WYs, respectively), measured upslope infiltration and sediment yield results from rainfall simulations studies, and assumed urban area loadings based on Loading Simulation Program in C++ or (LSPC)[1] sediment yield coefficients and results of urban runoff studies by Heyveart et al. (2008). These latter loading factors are our best first approximation and can be modified as additional field data and information applicable to the HMR Ski Area Master Plan Area (project area) become available. We suggest that the process described in this document may be the most robust approach to existing conditions calculations that has been done in the Lake Tahoe-Truckee region. The foundation for this claim is that we have used real-time water quality data from the site, and we have linked that to actual climate data from wet and dry years in order to estimate the variance between types of WYs. We have also used field-data adjusted smaller BMP functionality parameter values related to soil storage capacities and infiltration rates under wet and dry conditions in order to incorporate additional confidence in the values stated. This approach, as far as we know, has not been used before and sets a standard that we believe will offer a clear understanding of a starting point for water quality improvement designs for the project area.

An extremely important component of completing the work we have started here is monitoring of the actual implemented project and adjustment and refinement of system elements if needed. This is the accountability portion of the project. We are developing an applied adaptive management

[1] LSPC is the model used for the Lake Tahoe Basin Total Maximum Daily Load (TMDL) sediment reduction estimates and thus provides a high level of robustness and TMDL connectivity to this analysis.

strategy that will identify exactly how the performance of the systems are actually measured so that we can test our assumptions about model factors and adjust these factors, or systems to obtain the output needed, if adjustment becomes necessary.

Perhaps the most important element of our design, besides the robust estimates of performance that this document presents, is the fact that we have designed the system to treat more than the 'TRPA design storm' or the 20-yr storm. We recognize that episodic, high flow runoff events typically cause a greater impact than a 1–inch, 1-hour rainstorm, as was experienced in October 2009 where a 2+ inch storm resulted in a great deal of water quality degradation in the Lake Tahoe Basin. As Basin climate change continues, Coates (2010) noted that the relative frequency of larger storms is increasing as is the proportion of rain relative to snow events suggesting that larger capacity and more robustly designed stormwater collection/treatment systems will be required. Further we believe, based on a large body of data and observation, that the 20-yr storm design criteria may be inadequate to meet water quality protection needs, and therefore, the Project has increased the stormwater treatment system capacities beyond that of the standard design criteria.

What is the benefit of the proposed Stormwater Management program (SWMP) for the Project Alternatives vs. implementation of the standard 20-yr design requirement?

Dr. Mark Grismer PE and Michael Hogan (MS) of Integrated Environmental Restoration Services (IERS) worked with the information generated by Nichols Consulting Engineers (Nichols) describing existing conditions, the minimum 20-yr design storm SWMP and the proposed SWMP for Alternatives 1, 3 and 5 (Project SWMP) as a starting point for localized catchment modeling of the four redevelopment areas within the overall project area referred to as the North, South and Mid-Mountain Base Areas, and the Tahoe Skibowl Road Area. The Project SWMP design includes deployment of such LID (Low Impact Design approaches) elements as rainwater cisterns, pervious pavers and bio-retention areas for stormwater treatment together with upslope soil rehabilitation and larger capacity infiltration galleries than that required by the 20-yr storm BMP SWMP design. In the 20-yr BMP SWMP design, the higher infiltration rates within the underground galleries as suggested by TRPA specifications are accepted for modeling purposes, though in the Project SWMP design modeling, smaller, more realistic rates are employed. In both cases, all infiltration rates associated with LID type strategies (e.g. pervious pavers), basins and galleries are reduced by 50% under repeated wet conditions (e.g. sequential storms, spring snowmelt) in order to represent the effects of actual antecedent moisture conditions.

We consider four WYs in the modeling analyses and the daily precipitation data for these years was developed from the SNOTEL/PRISM modified Tahoe City data taken from the Pollutant Load Reduction Model (PLRM) cell #144. We examined the rainfall records used in the previous TMDL analyses (1993-2004) and identified the 1993-94 and 1994-95 water years as "dry" and "very-wet" years as well as 2002-03 and 2005-06 as more recent similarly "dry" and "wet" water years. For comparison purposes, Figure 1 illustrates the accumulated precipitation for Tahoe City and HMR. Note that the adjusted precipitation at HMR always exceeds that at Tahoe City by ~13 to ~35% for wet and dry WYs, respectively. Additionally, the storm distributions during each of these years vary, which in turn affects the amount of runoff and sediment loading generated. In Figure 1, observe that steeper step-wise increases are associated with repeated storm events. Note that the rainfall of recent "dry" years is similar to the 1993-94, though more rapid accumulations of precipitation occur early, mid and later in the WY. Similarly, though the Thanksgiving to New

Years rains of 2005 were substantial and resulted in significant stormwater contamination and slope failures in and around the Tahoe and Truckee region, the net accumulation is less than that of the 1995 WY.

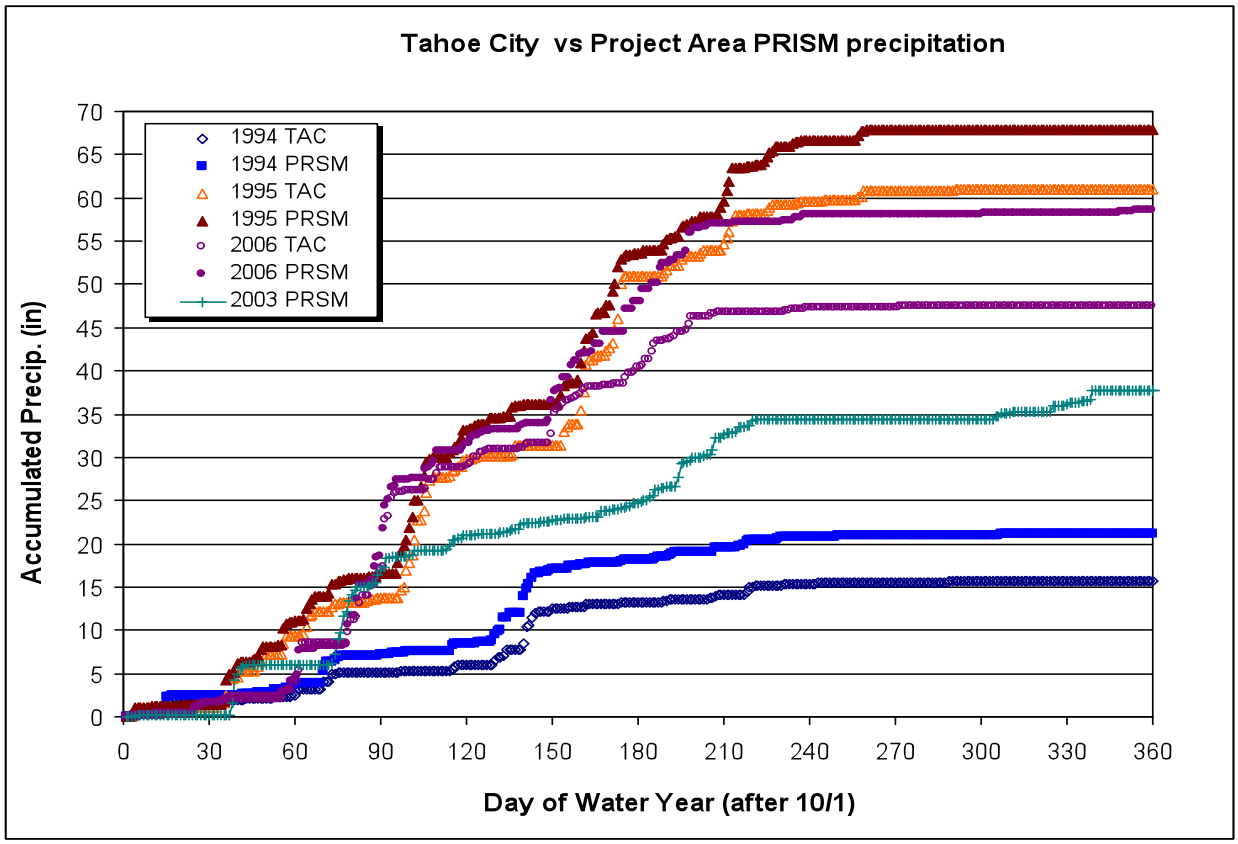


Figure 1. Comparison of Tahoe City (TAC) accumulated precipitation with PLRM estimates at the Project Area.

Excess Runoff and Sediment Load Modeling Calculations

Comparison of the Project *vs.* the 20-yr BMP SWMP's and existing conditions hydrology calculations provides a clear understanding of the benefits of the Project in terms of volume of water and sediment, fines and nutrient loads leaving the four redevelopment areas during wet and dry WY precipitation conditions. This stormwater management analysis relies on three tracks of information associated in part with some of the TMDL-related studies of 2007-2008. First, we assembled the sediment yield results developed from rainfall simulations at the project area to determine the sediment loads from the upslope areas. We combined this with the sediment yield factors (sediment loading factors per unit runoff) used in the Homewood Creek LSPC TMDL modeling to represent the urban areas, and finally, used the more complete runoff, sediment, nutrients and flow measurements completed by Desert Research Institute (DRI) researchers (Heyveart et al., 2008) for 2007-2008 to represent the nutrient loadings (see Figure 2). The DRI study was in the Brockway – Crystal Bay area of the Lake Tahoe north shore and represents actual field runoff and sediment behavior and characteristics over an extended period of time. While that data may not be completely representative of the west shore conditions, it is the only complete event driven data set of urban runoff available within the Lake Tahoe Basin, and thus allows a

more accurate foundation for analysis than previously available. Complete flow and concentrations measurements were captured by DRI for 12 storm events through January 2008. From these data, the sediment and nutrient loads per runoff event can be determined and related as shown in Figure 2. From the basic regression relationships and computation of sediment loads, associated nutrient loads can be estimated.

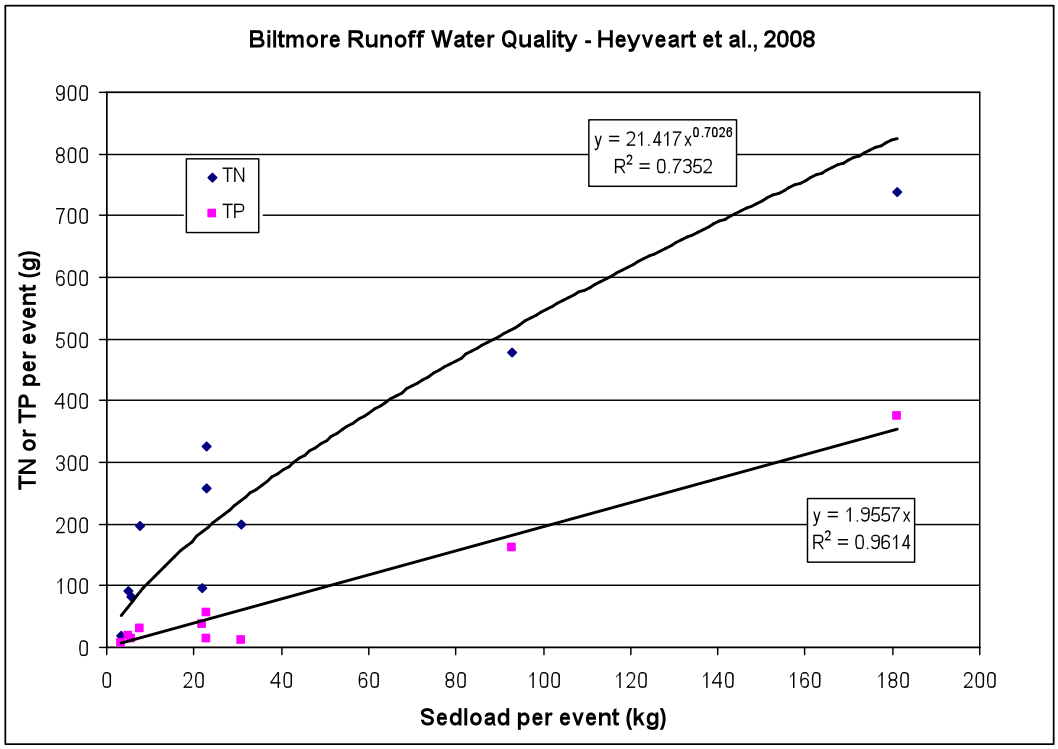


Figure 2. Relationships between nutrient and sediment loads per runoff event in 2007-08 at the Brockway-Crystal Bay area.

The second part of this analysis involved developing a routing/water-balance model of stormwater runoff from the redevelopment areas using modified rainfall records as described above. For comparison purposes, runoff areas between the three conditions were the same, although existing conditions have smaller impervious or somewhat different actual areas or locations. Annual stormwater infiltration, storage and runoff quantities are affected by daily changes in rainfall, snowmelt and available facility capacities throughout the year, with generally less capacity available during spring snowmelt periods and/or during sequential storm periods due to nearly saturated soil conditions.

Table 1 summarizes the net excess stormwater volumes and Table 2 lists the Project improvement compared to the existing conditions and the 20-yr BMP SWMP conditions. Excess stormwater runoff, that is, that volume not infiltrated or otherwise captured, is greatest from the 20-yr BMP conditions because they reflect the increased impervious surface areas as compared to existing conditions. This is particularly evident at the North and South Base areas and much less so at the Mid-Mountain Base and Tahoe Skibowl Road areas. At the Mid-Mountain and Tahoe Skibowl Road areas, the 20-yr BMP design does not include the uphill runoff that may enter the project area and must be contained by the redevelopment SWMP that is included in the Project SWMP analysis. As a result there is a net greater excess runoff from the 20-yr BMP SWMP than that from the Project SWMP at the Mid-Mountain Base area. In the Tahoe Skibowl Road area, there is

sufficient "over-design" under Project SWMP conditions to contain the uphill runoff such that there is still a slight improvement over 20-yr BMP SWMP conditions (3.3-7.8% improvement). Stormwater management under existing conditions was assumed to meet the 20-yr BMP criteria for the redevelopment areas based on current impervious coverage with the exception of the South Base area where information was available about stormwater vaults installed in 2006 and the capacities. As a result, we focus our comparisons between the Project and 20-yr BMP SWMP conditions to indicate the value of the Project as compared to the 20-yr BMP SWMP conditions because they reflect known conditions as yet to be implemented.

Table 1. Annual excess stormwater volumes leaving redevelopment areas for Existing, 20-yr BMP and Project SWMP designs in the wet (1995 & 2006) and dry (1994 & 2003) WY analyses.

Project Area	Existing Conditions (ft^3)				20-yr BMP SWMP (ft^3)				Project SWMP (ft^3)			
	1994WY	1995WY	2003WY	2006WY	1994WY	1995WY	2003 WY	2006WY	1994WY	1995WY	2003WY	2006 WY
North Base Area	86,621	1,063,148	431,469	1,085,104	176,359	1,423,567	612,899	1,444,862	11,130	696,946	240,951	662,489
South Base Area	12,311	431,985	151,781	419,998	91,653	762,996	326,481	771,149	6,420	380,941	132,462	352,956
Mid-Mtn Base Area	9,094	121,508	46,399	116,377	10,871	156,245	59,657	163,245	19,404	145,140	50,629	119,981
Tahoe Skibowl Rd	44,495	359,373	153,662	336,298	58,588	466,268	201,326	462,409	54,127	450,751	189,746	426,323
Overall	**154,514**	**1,978,010**	**785,314**	**1,959,783**	**339,466**	**2,811,071**	**1,202,365**	**2,843,670**	**93,076**	**1,675,773**	**615,791**	**1,563,755**

Table 2. Decrease in stormwater volumes leaving development areas for Project over 20-yr BMPs SWMP designs in the wet (1995 & 2006) and dry (1994 & 2003) WY analyses.

Project Area	Project SWMP (ft^3)							
	1994 WY	% Change	1995 WY	% Change	2003 WY	% Change	2006 WY	% Change
North Base Area	165,229	93.7%	726,621	51.0%	371,948	60.7%	782,373	54.1%
South Base Area	85,233	93.0%	382,055	50.1%	194,019	59.4%	418,193	54.2%
Mid-Mtn Base Area	-8,533	-78.5%	11,105	7.1%	9,028	15.1%	43,264	26.5%
Tahoe Skibowl Rd	4,461	7.6%	15,517	3.3%	11,580	5.8%	36,086	7.8%
Overall	**248,384**	**73.2%**	**1,137,293**	**40.5%**	**588,577**	**49.0%**	**1,281,922**	**45.1%**

Analogous to Tables 1 and 2, Tables 3 and 4 summarize the annual sediment loads for the redevelopment areas associated with the 20-yr BMP and Project SWMP designs. First considering dry WYs and focusing on the North and South Base areas, as they are the more substantial areas of the overall Project affecting loading and are adequate to illustrate the concepts, we show accumulated sediment loading in Figures 3a & 3b for the dry 1994 and 2003 WYs, respectively. In the 1994 WY, stormwater sediment load exceeds the 20-yr BMP SWMP capacities during 5-7 events at the two redevelopment areas as compared to only the one major event for the Project SWMP design capacities. As a result, the Project SWMP loads are 5.5% and 9.1% of the 20-yr BMP SWMP loads for the North and South Base areas, respectively. Note that the 2003 WY had greater overall precipitation as compared to the 1994 WY and this is reflected in greater loads under both SWMP designs. The occurrence of excess stormwater sediment loading events was roughly 3 times more often under the 20-yr BMP SWMP design conditions.

During the wet water years, stormwater runoff from the redevelopment areas would occur less than half as frequently (<10) under Project SWMP design conditions as compared to that for the 20-yr BMP SWMP conditions. Most stormwater runoff from the redevelopment areas occurs under Project SWMP conditions only for a substantial rain on snow event of 5.37 inches on New Year's Eve of 2005 and after sequential ~ 2 inch rain-on-snow days in January 1995 (recall that the 20-yr, 1-hr design storm event is 1.0 inches). Although fines (<16 μm) fractions of the total sediment load from the upslope areas above the North & South Base areas are between 40-55%, those from the redevelopment areas are assumed to be far greater, perhaps as high as 90%, but no such data is available for the HMR project area. Finally, additional tables analogous to Tables 3 and 4 as well figures analogous to Figures 3 and 4 can be generated from the modeling effort for the nutrient loads assuming applicability of the information of Figure 2 to the project area.

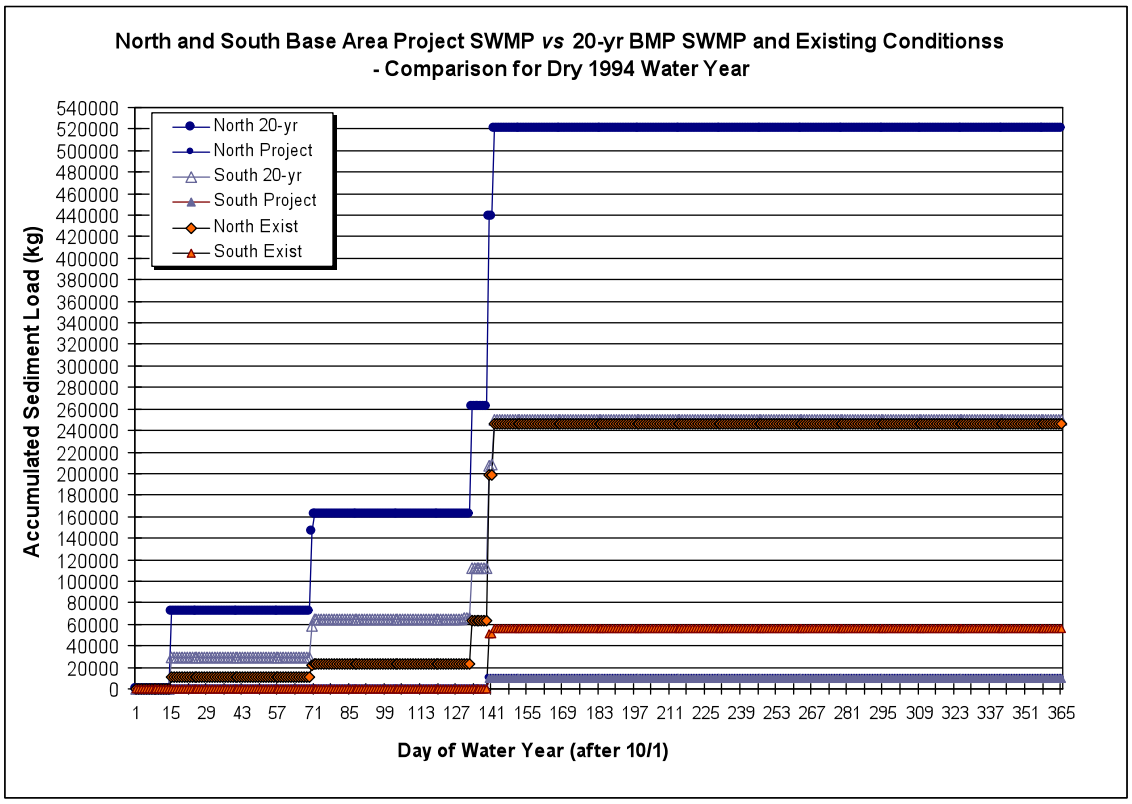
Figure 5 illustrates the possible accumulated nutrient loads from the North Base area under 20-yr BMP and Project SWMP conditions for the very-wet 1995 WY. While the graphs illustrate the basic concepts, the loads should be viewed with caution as they are based on the data shown in Figure 2 for the north Lake area rather than the west-shore. In the HMR redevelopment areas, the total land areas and sediment loads upon which these nutrient loads are estimated are much greater than that encountered at Brockway-Crystal Bay and likely beyond the event load data range shown in Figure 2. Nonetheless, they provide the reader some insight in the possible nutrient load variability that may be found at the HMR development areas.

Table 3. Annual excess stormwater sediment loads leaving development areas for Existing, 20-yr BMP and Project SWMP designs in the wet (1995 & 2006) and dry (1994 & 2003) WY analyses.

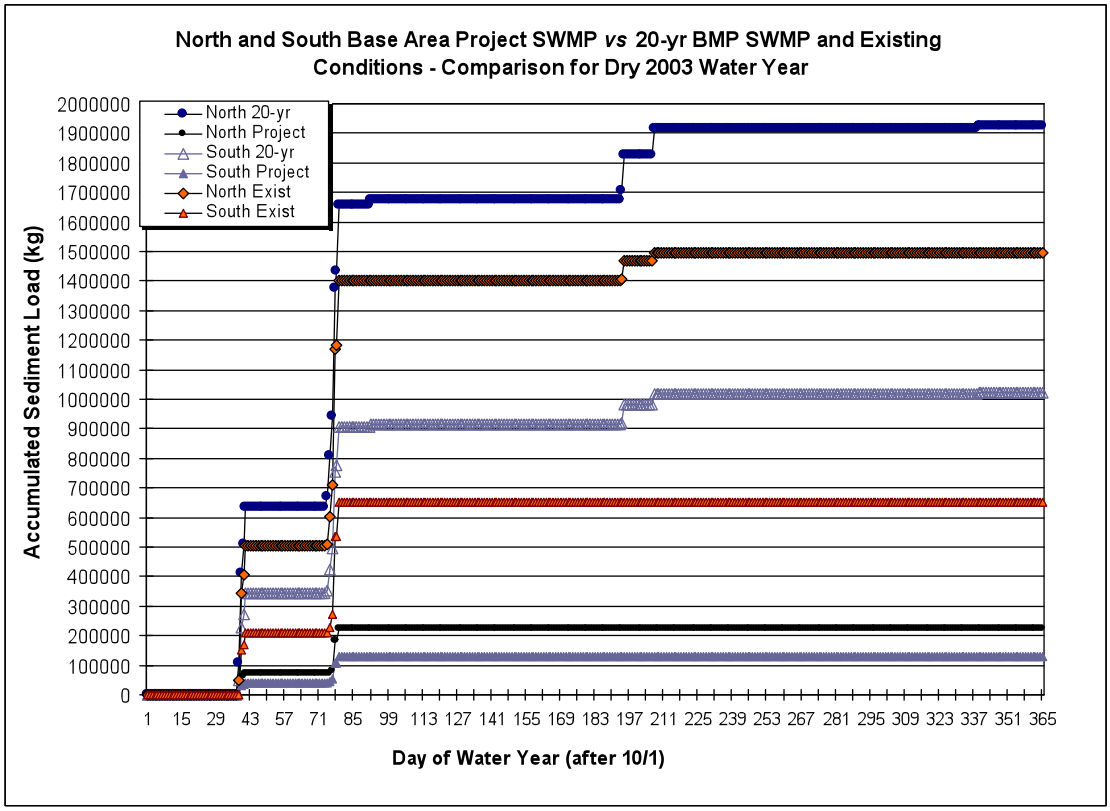
Project Area	Existing Conditions (kg)				20-yr BMP SWMP (kg)				Project SWMP (kg)			
	1994WY	1995WY	2003WY	2006WY	1994WY	1995WY	2003WY	2006WY	1994WY	1995WY	2003WY	2006WY
North Base Area	246,584	3,749,270	1,496,700	3,715,798	520,583	4,489,815	1,925,338	4,387,778	10,339	652,201	222,518	646,511
South Base Area	56,549	1,851,045	651,730	1,800,059	249,545	2,420,741	1,023,528	2,411,095	9,479	372,205	131,627	368,548
Mid-Mtn Base Area	15,353	475,818	166,708	461,902	21,493	491,426	177,498	497,680	28,649	187,886	68,063	162,855
Tahoe Skibowl Rd	98,685	1,324,050	522,235	1,260,036	100,199	1,209,091	492,269	1,125,043	72,542	510,820	219,642	491,384
Overall	**419,165**	**7,402,179**	**2,839,377**	**7,239,801**	**893,813**	**8,613,068**	**3,620,637**	**8,423,602**	**123,003**	**1,725,107**	**643,854**	**1,671,304**

Table 4. Decrease in stormwater sediment loads leaving development areas for Project over 20-yr BMPs SWMP designs in the wet (1995 & 2006) and dry (1994 & 2003) WY analyses.

Project Area	Project SWMP (kg)							
	1994WY	% Change	1995WY	% Change	2003WY	% Change	2006WY	% Change
North Base Area	510,243	98.0%	3,837,614	85.5%	1,702,820	88.4%	3,741,267	85.3%
South Base Area	240,065	96.2%	2,048,536	84.6%	891,901	87.1%	2,042,547	84.7%
Mid-Mtn Base Area	-7,156	-33.3%	303,540	61.8%	109,435	61.7%	334,825	67.3%
Tahoe Skibowl Rd	27,657	27.6%	698,271	57.8%	272,627	55.4%	633,659	56.3%
Overall	**772,804**	**86.5%**	**6,889,956**	**80.0%**	**2,978,786**	**82.3%**	**6,754,304**	**80.2%**

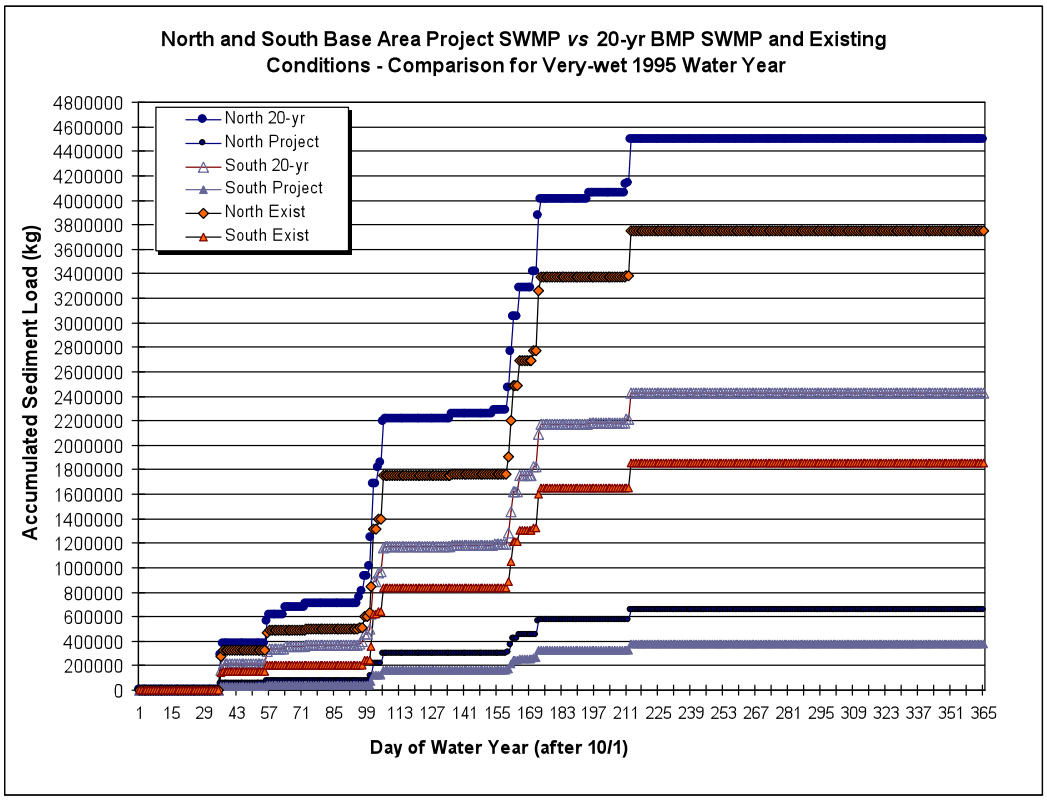


(3a)

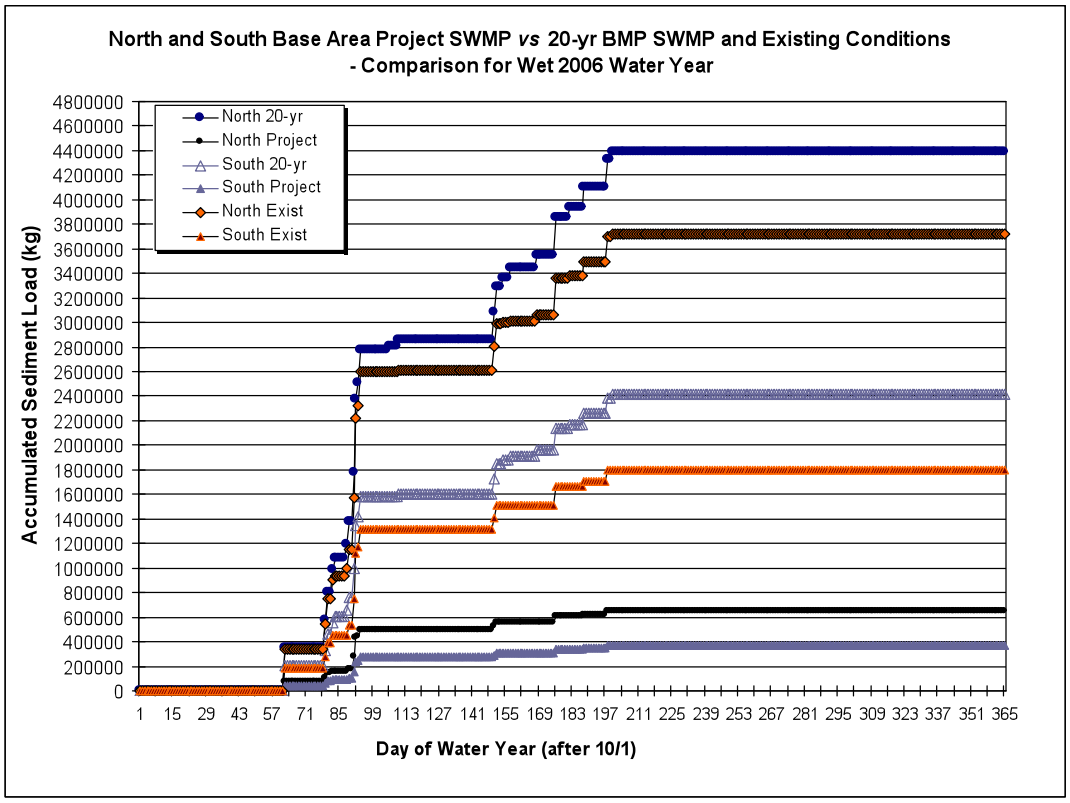


(3b)

Figure 3. Accumulated possible sediment loads leaving redevelopment areas under dry WY conditions for the North and South Base areas.

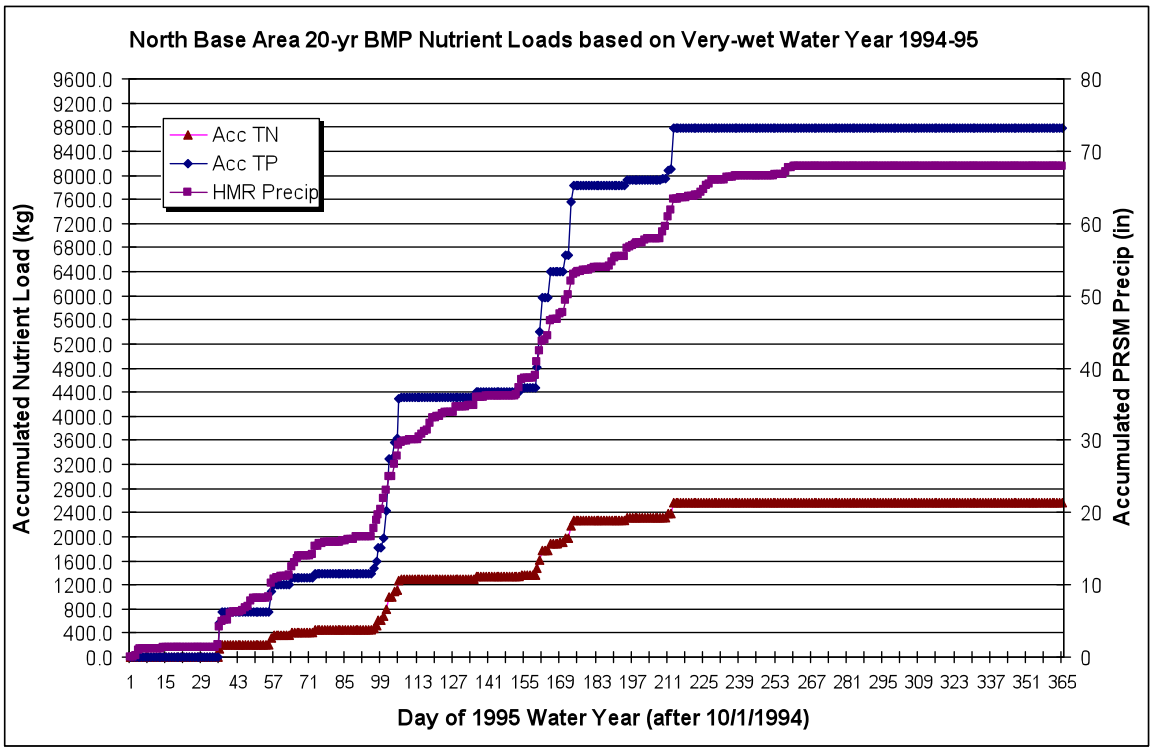


(4a)

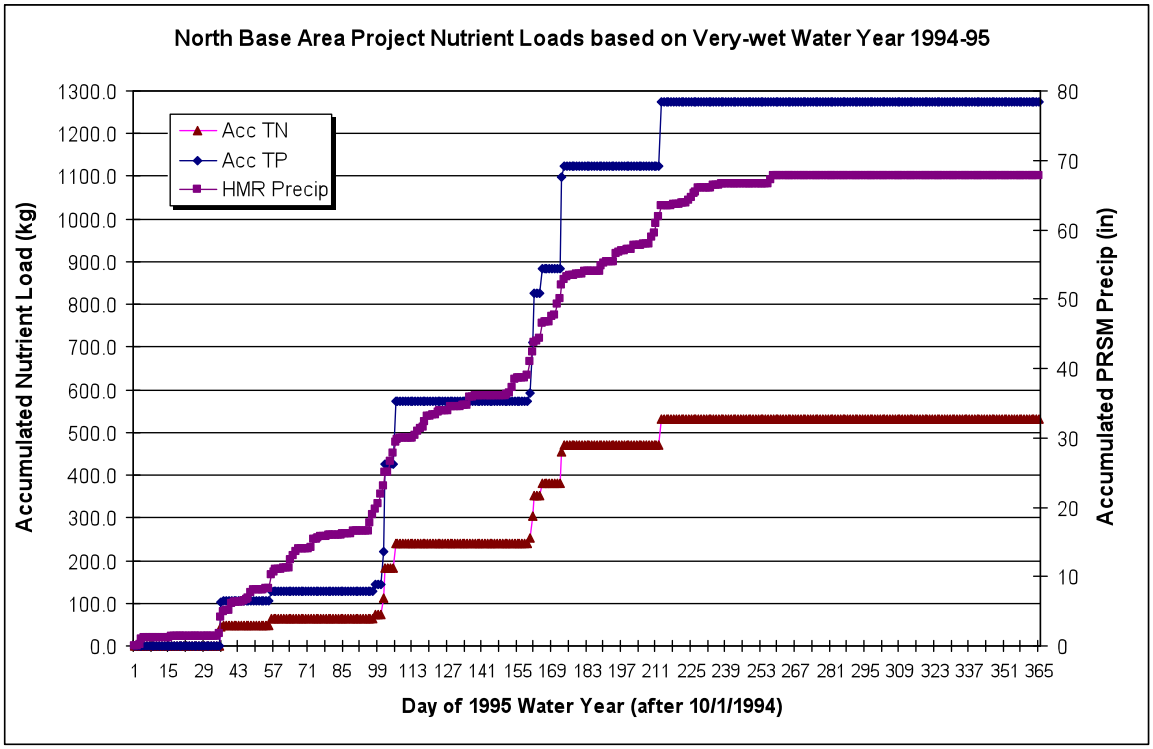


(4b)

Figure 4: Accumulated possible sediment loads leaving the redevelopment areas under wet WY conditions for the North and South Base areas.



(5a)



(5b)

Figure 5: Possible accumulated nutrient loads leaving the North Base redevelopment area under 20-yr BMP SWMP (a) and Project SWMP (b) conditions for the very-wet 1994 WY.

Summary

The stormwater runoff and treatment efficiency that can be expected from the Project SWMP is presented here in a manner similar to that for the Boulder Bay project on the Lake Tahoe north shore. Using measured infiltration and sediment yield data and daily climate data for a range of WYs and conditions, we have calculated and compared the runoff from 20-yr BMP SWMP and Project SWMP design conditions. While simple summary statements are difficult to make, given the complexity of storms, antecedent soil moisture conditions and other variables, the data shows that in wetter years, which represent worst-case scenarios, sediment and presumably fine sediment loads from the Project SWMP design are 80-86% less than those produced by the standard 20-yr BMP SWMP design.

Citations

Coates, R. 2010. Climate change in the Tahoe basin: regional trends, impacts and drivers. Climatic Change DOI 10.1007/s10584-010-9828-3. April.

Heyveart, A.C., A.T. Parra, C.C. Strasenburgh and R.P. Townsend. 2008. Brockway Project Area Stormwater Runoff and Characterization Study. UN- Desert research Institute, Reno, NV. March.